Control of Random Cracking in Concrete Residential Pavements

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Abstract: AS 3727.1 Pavements Part 1: Residential was revised in 2016 and changed from a guidance document to a mandatory Standard. It includes some significant changes that will affect the way that typical residential concrete pavements are required to be constructed, particularly with reference to typical joint details. Changes to the joint details, spacing and reinforcement, were considered necessary to limit what is now referred to in the Standard as random crack widths, for which the performance limits have been reduced from 1.5 mm to 1.0 mm for consistence with other Standards that cover residential concrete work.

The question remains as to what is considered an acceptable random crack width for exterior pavements, should the acceptable width be based on the type of cracking, and how do the new provisions address this important issue for home owners. Cracking in decorative driveways remains one of the largest areas of concern to, and source of complaints by home owners, as it remains one of the largest investments made by owners. As such, there is an expectation by owners that the finish will not be affected by unsightly cracking.

This paper addresses the question of what should be regarded as an acceptable random crack width from both a home owner and industry perspective, should particular types of cracks, even though wider, still be regarded as acceptable, and how effectively do the new provisions in AS 3727.1 either prevent the occurrence of random cracking, or if cracks occur, control the width of those cracks in order to satisfy the new performance limit and owners expectations.

Keywords: Cracking, Pavements, Joints, Quality

1. Introduction

Cracking of residential driveways and paths is a major source of complaints. Home owners who have invested a significant amount in the construction of pavements around their homes, generally do not expect to see any cracking, and yet builders and concreters maintain that all concrete shrinks and not only should cracks be expected, they should be considered as a natural part of any concrete pavement. The issue is complicated by the fact that assessing whether cracking is acceptable is largely subjective: to homeowners any cracking at all may be unacceptable, and seen as similar to a defect in a purchased item. There is generally a lack of information available in Australia on what should be considered aesthetically acceptable, as the performance limits in Australian Standards such as AS 3727 *Guide to residential pavements* (1) and various industry guides do not consider the aesthetic acceptability of cracking, but only whether the crack width indicates a possible serviceability problem.

The physical requirements for pavements are contained within AS 3727, and basic quality issues such as ensuring the steel reinforcement is at the correct height within the pavement and the compaction and curing of the concrete are specified. Good work practices can have a significant impact on minimising the extent and width of any cracking that may occur.

This paper addresses the issue of what an aesthetically acceptable crack width is; how effective the new provisions in AS 3727 might be in controlling cracking to an aesthetically acceptable limit; and some of the basic quality issues that need to be addressed to reduce the risk of random cracking of residential pavements.

2. Aesthetically acceptable crack width

The 1993 version of AS 3727 included a crack width limit of 1.5 mm for bound pavements. This has been reduced to 1 mm to be consistent with limits in AS 2870 (2). As it was not clear what type of crack the width limit referred to, a new definition of random crack was introduced into AS 3727 to describe those cracks that occur in between or away from planned joints and which may be regarded as aesthetically unacceptable by homeowners.

The width of cracks that occur at predetermined locations (control and construction joints) is not considered to be an issue for typical residential pavements having joints at reasonably close centres, as the cracking follows straight lines at locations that are intended to crack and can be sealed if required to improve the appearance. The 1 mm limit on random crack width is intended to indicate the possibility of a serviceability problem and need for assessment of the paving, and not necessarily intended to provide guidance on what could be considered an aesthetically acceptable crack width.

While largely subjective, there are many references in overseas Codes and Standards as to what should be regarded as an aesthetically acceptable crack width limit. Clearly, when performance limits for aesthetics are compared to the serviceability limits, there is a large disconnect between what the 'industry' deems an acceptable crack width (and extent of cracking) for serviceability, and what homeowners think is reasonable aesthetically, because they address different issues.

The United States National Association of Home Builders, who represent the majority of building contractors, publish a document known as the *Residential Construction Performance Guidelines* (3). The document was developed as both contractors and their customers were seeking "*measureable benchmarks that deal with the expectations of performance in the goods and services provided by the residential construction industry*". Under the section dealing with concrete driveways and sidewalks, cracks (away from control joints) are considered excessive if they "*exceed 6 mm in width, or 6 mm in vertical displacement*".

From the concrete supply industry, the Illinois Ready Mixed Concrete Association publish a document called *Specifications for Residential Exterior Flatwork* (4), in which they provide some evaluation guidelines for exterior concrete. They state that "*Residential Exterior Flatwork shall be deemed acceptable when it does not display Major Cracking, Major Scaling, and Major Spalling due to defective materials or workmanship for the period of one year*." They define a major crack as "*An uncontrolled crack with a width of 3 mm or more that covers more than 10% of the total length of all the joints and edges of the slab and the total length is no more than 20% of the perimeter length of any one panel*." In terms of AS 3727 for a driveway having joints at 4.5 m centres, this means that the total length of 3 mm wide cracks in the panel can be 1.8 m: something that most homeowners would find aesthetically unacceptable. Interestingly, the period over which cracking can occur is limited to one year. This is the same as the new provision in AS 3727 and acknowledges that over long periods, many other factors such as poor maintenance and tree roots can cause significant cracking of exterior pavements.

The Ready-mixed Industry's 3 mm limit for paving is consistent with the American Concrete Institute's (ACI) *Guide to Residential Concrete Construction* (5) for house slabs, where it states "*Because concrete (plain or reinforced) does crack and cracking cannot always be avoided, shrinkage crack widths up to 3 mm should be considered normal and acceptable (tolerable)*". From a home owner's perspective, what should be considered as 'normal and acceptable (tolerable)'?

Eurocode 2 (6) states in Clause 7.3.1 that: "*Cracking shall be limited to an extent that will not impair the proper functioning or durability of the structure or cause its appearance to be unacceptable*." Table 7.1N of Eurocode 2 includes a crack width of 0.4 mm which is "*set to guarantee acceptable appearance*." This is consistent with the ACI (7) crack width limit of 0.4 mm considered acceptable for concrete structures.

British Standard BS 8110 (8) also states in Clause 3.2.4.1 that: "*For members that are visible, cracking should be kept within reasonable bounds…….maximum crack width should not exceed 0.3 mm*." Based on the above, 0.4 mm appears to be a reasonable width limit for an aesthetically acceptable crack, regardless of whether the crack is in a concrete structure or pavement.

In an attempt to capture the subjectivity of assessing if crack widths are acceptable, Campbell-Allen (9) developed a graph of viewing distance versus the 'prestige nature' of various building types **Figure 1**. For domestic buildings (and paving) a crack width of 0.4 mm would be regarded as acceptable at a viewing distance of about 2.5 m based on line 4 in **Figure 1**. As paving is normally viewed at a distance of 1.5 m to 2 m, it is not surprising that the owner considered the extent of cracking in **Figure 2** unacceptable and was reluctantly prepared to accept the cracking in **Figure 3**. Based on aesthetics, 0.4 mm appears to be a reasonable crack width limit and is significantly less than the reduced serviceability limit of 1 mm now in AS 3727.

3. Performance Limits for Cracking

The performance limit with respect to random cracking in the revised AS 3727, which is now a mandatory Standard, has been reduced from 1.5 mm to 1.0 mm to be consistent with cracking limits in AS 2870 *Residential slabs and footings*, and a time limit of one year imposed to distinguish between causes related to serviceability issues and long-term maintenance factors. **Table 1** shows that the new limit of 1.0 mm is equivalent to a fine crack in a residential slab.

Government Authorities in NSW (10), Queensland (11), Victoria (12) and Tasmania (13) currently adopt the previous performance limit of 1.5 mm for residential paving. Paving is considered defective if the crack width as a result of the builder not making allowance for shrinkage or general movement of the concrete, exceeds this 1.5 mm. In future revisions, this is expected to reduce to the new limit of 1.0 mm within the first year.

This paper outlines how the provisions in the revised AS 3727 seek to reduce the risk of random cracking and control any cracks that do occur to within the serviceability limit. The paper also reviews the possibility of complying with an aesthetically acceptable crack width.

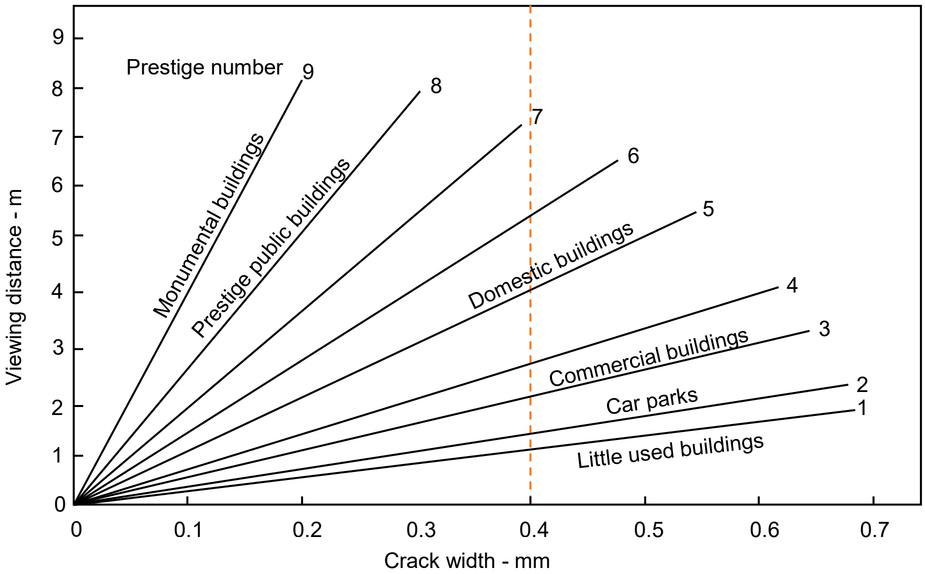

Figure 1 Visual assessment of crack widths (9)

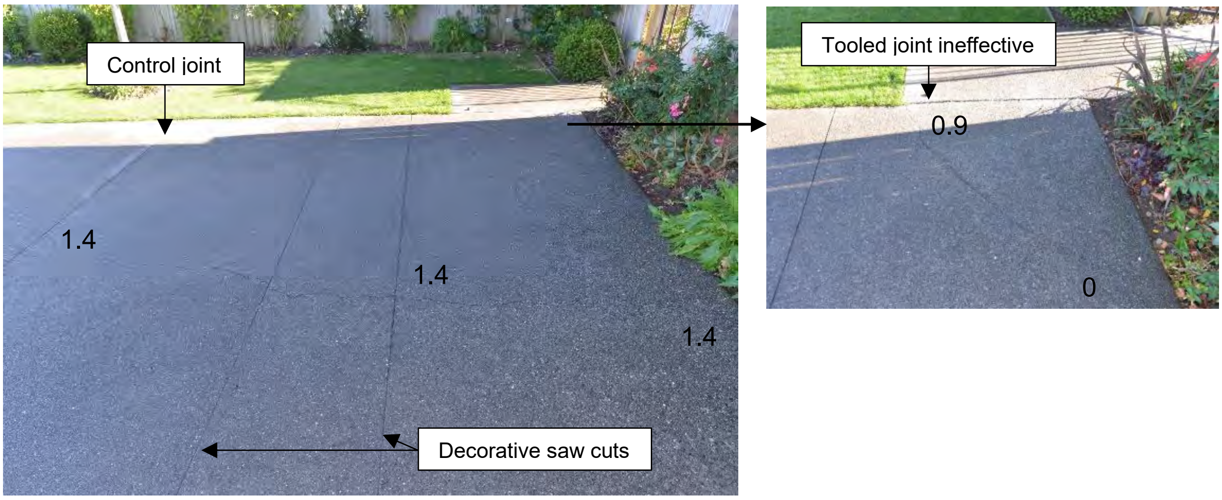

Figure 2 Example of cracking to driveway

Figure 3 Example of cracking to patio slab

Table 1 Damage categories for slabs in AS 2870 (2)

Description of typical damage	Approximate crack width limit	Change in offset in 3 m straight edge	Damage category
Hairline crack	< 0.3 mm	< 8 mm	0
Fine crack	< 1.0 mm	< 10 mm	1
Distinct crack	< 2.0 mm	< 15 mm	2
Wide crack	2 – 4 mm	15 – 25 mm	3
Gaps in slab	4 – 10 mm	> 25 mm	4

4. Types of cracks in pavements

There are many different types of cracks that can occur in a concrete pavement from factors such as plastic surface shrinkage, plastic settlement, long-term drying shrinkage, ground movement and/or loss of support, reduction in bearing capacity (including saturation from poor drainage), influence of tree roots, over-loading, restraint, thermal movement and poor joint detailing/layout. The Concrete Institute (14) state that '*crack widths measured on site are not the result of any one cause*', suggesting that if cracking occurs, they are typically the result of two or more factors that cause some of the above types of cracks. The random cracking referred to in this Standard is related to the long-term drying shrinkage of the concrete, and not one of the other causes listed above or as a result of poor quality construction practices.

While reinforcement in a slab on ground will not prevent random cracking, it is used to control the width of any random cracks that may occur. Note that reinforcement is also effective in controlling many other types of cracking.

5. Provisions to reduce risk of random cracking of concrete pavements in AS 3727

There have been a number of significant changes to the way concrete pavements are to be constructed in the 2016 revision of AS 3727. These include:

a) The maximum joint spacing for reinforced pavements has been reduced from either 6 m to 4.5 m, or 3 m to 2 m depending on the mesh size used, and 2 m to 1.5 m for unreinforced pavements up to 100 mm thick. ACI 224R-01 (15) states that: "*Shrinkage and thermal contraction cracks are remedied or eliminated by appropriate construction procedures, such as joints*…" Dividing the pavement into reasonably small sections is thus one of the preferred ways to reduce the risk of random cracking.

   The new recommended maximum spacing is based on years of evaluation and practical experience with concrete pavements in Australia. ACI 360R-10 (16) and the Portland Cement Association (17) recommend that the maximum joint spacing for an unreinforced concrete pavement is 24 to 36 times the slab thickness. For large aggregates and low water:cement ratios, the upper end of the range would be appropriate, and for the smaller aggregate sizes typically used in Australia, and common practice of adding water to the concrete on site (increasing the water:cement ratio), the lower end of the range would be appropriate. Hence for a 100 mm thick pavement, a joint spacing of about 2.5 m would be reasonable to reduce the risk of random cracking. Note that research into control joint spacing by Miltenberger and Attiogbe (18) found that providing reinforcement only allowed a marginal increase in the joint spacing (refer item (b)).

   While random cracking from a range of quality issues can occur in any concrete pavement, the new 4.5 m maximum joint spacing for a 100 mm thick and 150 mm thick pavement suggests that some random cracking may still occur. Thus it is important to also provide the minimum reinforcing mesh to ensure that the width of any random cracking is adequately controlled.

b) The reinforcing mesh sizes have generally been increase by one size to provide better control of the widths of any random cracks that may occur.

   The function of reinforcement in a pavement is not to contribute to the strength or eliminate/prevent cracking, but to hold tightly closed any random cracks that may form from the drying shrinkage of the concrete. The area of reinforcement (size of mesh) is related to the spacing of joints, as friction between the concrete pavement and ground can lead to tension in the concrete, which if greater than the strength of the concrete, can result in random cracking. Note that while AS 3727 provides the minimum requirements, for decorative pavements where any cracking tends to be more noticeable, the minimum reinforcement requirements provided may be increased (ie use a larger mesh) if greater crack control is required.

AS 2870 requires that where brittle floor coverings such as tiles are to be used over an area greater than 16 m^2, one of three measures must be considered: increase the reinforcing mesh to SL92, select an appropriate bedding system that allows sufficient movement and delay the placement of floor coverings to provide time for any shrinkage cracking to occur. The same approach may be considered for external paved areas that are to be tiled, topped with a decorative surface finish or that have an integral decorative topping provided.

c) Reinforcement will no longer be allowed to past through control joints. Control joints are installed in pavements to 'control' the location at which cracking from movement of the concrete occurs. Clause 5.4.2 of AS 3727 lists both formed and weakened plane type control joints. One of the options for weakened plane control joints allowed in the 1993 *Guide to residential pavements* was to extend the reinforcement through the joint and cut every second mesh bar to reduce the steel area at the joint location by 50% to create a 'weakened' plane that would promote cracking at the joint location. Many contractors adopt this practice to provide some mechanism of load transfer and control vertical movement across the joint, without the need to provide dowels. However, providing restraint at a joint intended to allow movement and thus control the location of cracking within a pavement, will increase the risk of cracking occurring at other than joint locations. If the concrete fails to crack at a particular joint location, the width of any random cracks will be increased. Combined with various poor quality construction practices such as incorrect cutting of the mesh, not cutting mesh bars in a straight line and late saw cutting, the Standard has removed the option of allowing reinforcing to pass through joints and clearly states in Clause 5.3 (g) that reinforcement shall not be continuous through control joints.

   With the removal of the ability to extend reinforcement through the joint to provide some load transfer, other options needed to be provided.

d) The option of providing dowels at weakened-plane joints (that otherwise only rely on aggregate interlock for load transfer) has been indicated in the AS 3727 figures. Section 6.6 of ACI 360R-10 suggests that large reductions in the load transfer capacity of joints occurs at relatively minor crack/joint widths: more than 40% reduction in load transfer for a 0.6 mm wide crack at the joint location. The effectiveness of load transfer increases with increasing slab thickness and improved ground conditions.

   With the risk that not all joints will crack and open up, leaving others with much wider cracks than expected, the provision of some form of load transfer device at all control joints is recommended. The two readily available options are pressed metal key joints (formed control joints) and dowels placed in weakened-plane joints.

   Both pressed-metal and dowel systems are available from numerous suppliers in the market at a price comparable with the cost of saw cutting the joints. These systems overcome many of the quality issues associated with weakened-plane joints.

e) Dowel size and spacing details. Table 5.4.4 of AS 3727 has been expanded to include both square and plate dowels, along with the previous round dowels, and notes have been provided for guidance on suitable applications for each dowel type.

   For larger pavements requiring joints in two orthogonal directions, movement along the joint as well as transverse to the joint needs to be considered. If dowels are used for load transfer across the joint, the improved selection now available in the Standard is of benefit.

f) The concrete strength required has been increased from 20 MPa to 25 MPa for pavements used by light vehicles and from 20 MPa to 32 MPa for pavements used by commercial vehicles, bringing the requirements into line with the AS 3600 (19) provisions for abrasion resistance.

   A higher strength concrete will reduce the risk of random cracking by allowing the concrete to carry more tensile stress developed from the friction with the ground, before cracking.

The new requirement not to extend reinforcement through joints will have a significant impact on reducing the risk of random cracking, as the joints will now be free to move. The combination of decreased joint spacing and increased concrete strength will also reduce the occurrence of random cracking, and should one occur, the increased reinforcement size/area will have greater capacity to hold the crack tightly closed. The provision of load transfer devices at joints (pressed metal or dowels) will compensate for not being able to extend reinforcement through the joint and depending on the joint type selected, reduce the typical random cracking problems that occur by saw cutting too late.

The changes to AS 3727 will reduce the risk of random cracking, however, there are a number of basic quality issues that should also be addressed to further reduce the risk of random cracking.

6. Importance of good construction practices

Good construction practices are assumed by Standards in order to meet requirements but are often overlooked by contractors working in a cost-driven environment where home-owners think that regardless of the cost, the quality will be the same. In some instances, price may not reflect quality either. Some of the basic quality issues include:

6.1 Preparation prior to concreting

As the main function of the reinforcement is to hold tightly closed any random cracks that may form, and as cracks are seen at the top of the pavement, the reinforcement should also be close to the surface of the slab. The Concrete Institute (14) state that '*The ability of reinforcement to control the width of cracks at the surface of concrete is a direct function of cover*'. AS 3727 specifies a concrete cover of 30 mm to the surface of the slab, typically placing the reinforcement in the top half of the slab.

Reinforcement must be located at the correct height using bar chairs complying with AS 2425 (20). Reinforcement must not be left on the ground and either hooked up at the time of placing concrete or 'walked in' to the plastic concrete **Figure 3**. There is no way of ensuring that the reinforcement ends up in the required location by adopting such practices. Reinforcement is often not chaired to allow concrete trucks access to place the concrete (**Figure 4**), but reinforcement must be chaired to the correct height prior to placement of the concrete.

Reinforcement must be adequately lapped where sheets of mesh or bars are joined. For mesh, the requirement is that the two outermost wires of one sheet should be overlapped with the two outermost wires of the next sheet of mesh **Figure 5**. For bars, the minimum lap provided must at least 29 times the bar diameter.

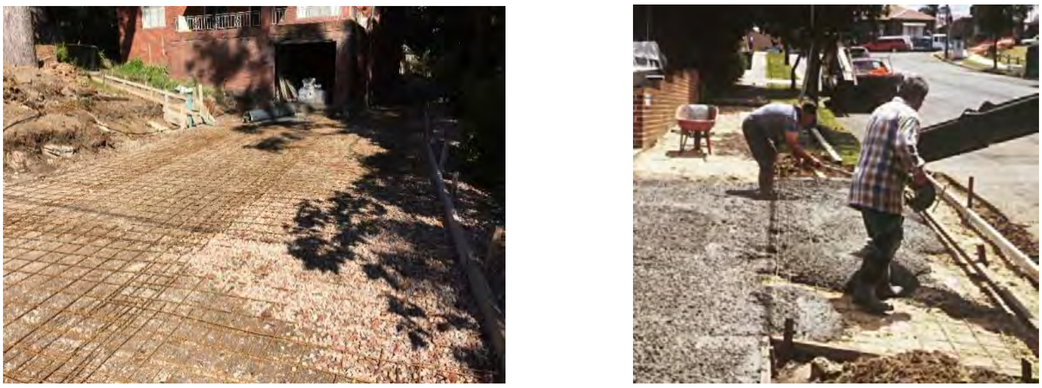

Figure 3 Reinforcement must be chaired at the correct height prior to placing concrete

Figure 4 Inadequate lapping of mesh at corner

Figure 5 Inadequate lapping of mesh at corner

Proper ground preparation, ensuring that the surface is relatively smooth and free of depressions will help to prevent the concrete binding to the surface, decreasing the friction between the concrete slab and ground, and in turn, decreasing the risk of random cracking. If required, a levelling sand layer could be considered under the pavement to reduce the friction and allow better movement of the concrete as it shrinks due to drying. The provision of a plastic membrane will further reduce the friction and risk of random cracking.

The ground should also be free of any soft areas (such as that shown in **Figure 4**), to prevent the pavement cracking **Figure 5**. It is a common misconception that a rigid concrete pavement can span over softer areas of the ground.

Figure 5 Ensure the ground is free of softer areas that may cause future cracking

6.2 Uncontrolled addition of water to the concrete on site

Unless specifically ordered, concrete will be supplied with a slump of 100 mm. This should provide adequate workability without the need for concreters to add additional water on site, which will decrease the strength of the concrete and more importantly, increase the long-term drying shrinkage and hence risk of random cracking of the concrete. It may also cause increased settlement and risk of plastic settlement cracking, which typically resembles a grid of cracks that reflect the reinforcement location.

6.3 Compaction of the concrete

Compaction improves the strength of the concrete and minimises the risk of random cracking **Figures 6 and 7**. A lack of compaction can also lead to plastic settlement cracking. Adequate compaction of a 100-mm-thick concrete pavement can typically be achieved by the placing, screeding and finishing operations. For thicker pavements, mechanical vibration of the concrete is recommended to ensure adequate compaction.

Figure 6 Compaction of concrete decreases risk of random cracking

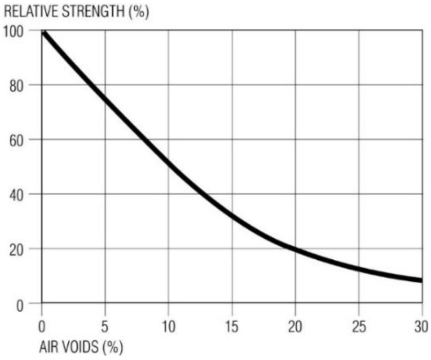

Figure 7 Lack of compaction significantly reduces strength

6.4 Curing

Adequate curing of the concrete also improves the concrete strength and is also a key quality issue that should be addressed to lower the risk of random cracking within the concrete. Curing, or keeping the concrete moist, allows the concrete to gain strength before it is allowed to start drying. As drying or losing moisture causes the concrete to shrink, the more strength it has, the better it is able to resist the tensile forces that result from the friction with the ground as it shrinks, and this can significantly reduce the risk of random cracking.

Two basic methods exist to cure concrete: add water to the surface of the concrete or retain moisture within the concrete.

If adding water to the surface, ensure that the surface is strong enough not to be damaged by the water. This may leave the concrete exposed for a critical period of time, particularly on hot, windy days and increase the risk of surface drying shrinkage cracking, which is often mistaken for random cracking due to long-term drying shrinkage.

If retaining moisture by covering with plastic, clear or light coloured plastic should be used (**Figure 8**) and ensure that joins and edges are held down to avoid them lifting and the surface drying out. The use of chemical curing compounds in accordance with AS 3799 *Liquid membrane-forming curing compounds for concrete* (21) is a simple and effective option for curing concrete.

Plastic membranes and chemical curing compounds should be applied as soon as the concrete surface has been finished, to protect the surface from rapid drying and reduce the risk of random cracking.

AS 3727 specifies a minimum curing period of three days. However, longer curing periods are recommended.

The CCAA (22) carried out a survey of residential slabs-on-ground (up to 25 m in length with no joints) that were constructed in accordance with AS 2870 and addressed all of the above quality issues, and found that about a third of residential slabs-on-ground displayed no random cracking, and about 80% had cracks that did not exceed 0.4 mm in width **Figure 9**. The much closer joint spacing and detailing required for external residential pavements in AS 3727 suggests that if some basic quality issues are addressed during construction, typically no cracking should be expected, or if random cracking does occur, it should be less than what is considered an acceptable width aesthetically (0.4 mm).

Figure 8 Clear plastic recommended for curing

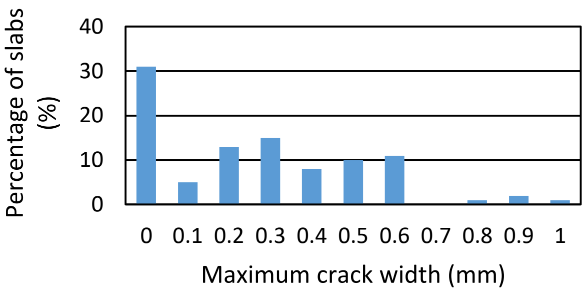

Figure 9 Cracking in residential slabs (22)

6.5 Joints

Two types of joints are covered in AS 3727: those that allow movement (isolation and expansion joints) and those that are intended to control cracking (control or contraction joints). Options for providing control joints include forming the joint, which is preferred as they provide separation over the entire slab depth (**Figure 10**), or creating a weakened plane within the concrete by saw cutting, tooling or inserting some form of crack inducer for a depth of one quarter of the slab thickness. As quality issues in weakened plane joints have the greatest potential to cause random cracking, formed joints are preferred, as they avoid the need to saw cut the slab.

Some of the basic quality issues relating to weakened-plane joints are discussed in Appendix B of AS 3727 and include:

- Provide at the required spacing **Figure 11**
- Ensure joints are continuous and do not crack adjacent slabs **Figures 12 and 13**
- Ensure that there are no small wedges of slab that can crack where joints intersect or meet the perimeter of the pavement. Clause 5.4.6 of AS 3727 recommends that ‘the angle formed between joints or between a joint and the edge of the pavement should not be less the 75°’ **Figure 14**
- If saw cut joints are provided, ensure saw cutting is carried out at an appropriate time and before the pavement has already cracked **Figure 15.** According to ACI 332.1R-06 (23), saw cutting should be completed between 4 and 12 hours (depending on the temperature) after

the finishing of the slab. Typically it is left considerably longer than this, significantly increasing the risk of random cracking.

- If dowels are provided, ensure the proper alignment both horizontally and vertically (by using dowel supports or cradles) to prevent dowel lock-up, and ensure that they are adequately coated or otherwise free to move to prevent cracking occurring away from the joint location **Figure 16**. The surface of dowels should be smooth and the ends cut square.
- If tooled joints are provided, ensure the depth of tooling is not filled with cement slurry, rendering the joint largely ineffective and increasing the risk of random cracking adjacent to the joint location **Figure 17**
- If inserting crack inducers in the surface of the slab, ensure they are the correct depth and installed in a straight line

Figure 10 Formed control joint using pressed metal key joint profile

Figure 11 Cracking due to excessive joint spacing

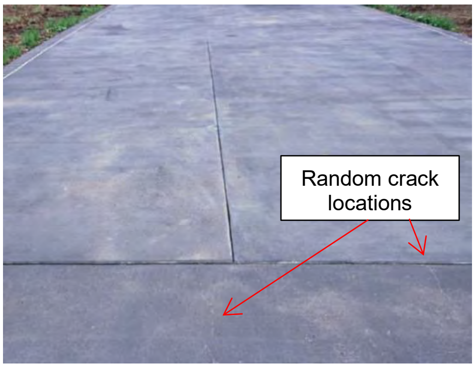

Figure 12 Ensure joints are continuous

Figure 13 Ensure joints are continuous

Figure 14 Ensure minimum 75° angle between joints or at edges

Figure 15 Cracking due to late saw cutting

Figure 16 Ensure dowels are properly coated and aligned

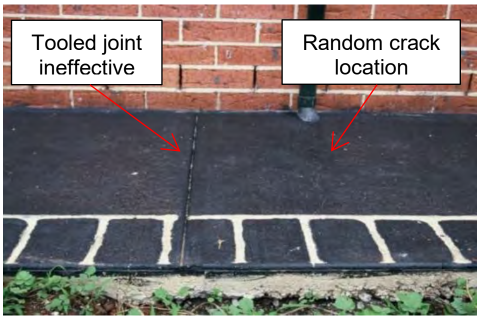

Figure 17 Ensure required joint depth when tooling joints

7. Conclusion

Adopting the new provisions of AS 3727 and ensuring that key quality issues are addressed should result in a crack-free pavement for at least the initial 12 month period and longer if maintenance issues are addressed. Having addressed the quality issues and constructed the pavement in accordance with the Standard, if random cracking does occur, the new provisions should control the width to an aesthetically acceptable limit of 0.4 mm. If it does not, and cracking wider than the performance limit of 1.0 mm occurs, then it is likely that there are other factors involved and an inspection should be arranged to determine the cause and any rectification necessary.

References

1 Australian Standards AS 3727 *Pavements Part 1: Residential*, 2016

2 Australian Standard AS 2870 *Residential slabs and footings*, 2011- Table C2

3 National Association of Home Builder, *Residential Construction Performance Guidelines* (Consumer Reference Fifth Edition, 2015), 1201 15th Street, NW, Washington, DC 20005-2800

4 Illinois Ready Mixed Concrete Association, *Specifications for Residential Exterior Flatwork*, 2013, 303 Landmark Drive, Suite 1-A, Normal, Illinois 61761

5 American Concrete Institute, ACI 332.1R-06 *Guide to Residential Concrete Construction*, 2008: Clause 6.7.1 *Cracking*

6 Eurocode 2 or BS EN 1992-1-1:2004 *Design of concrete structures. General rules and rules for buildings*, Eurocodes, 2004

7 American Concrete Institute, ACI 224R-01 *Control of Cracking in Concrete Structures*, 2008, Table 4.1 *Guide to reasonable crack widths*

8 BS 8110-2: 1985 *Structural use of concrete - Part 2: Code of practice for special circumstances*, British Standards, 1985

9 Prof. Campbell-Allen, Denison, *The Reduction of Cracking in Concrete*, University of Sydney (in association with the Cement & Concrete Association of Australia), 1979

10 Office of Fair Trading, NSW, Guide to Standards and Tolerances, 2007

11 Queensland Building and Construction Commission, *Standards and Tolerances Guide*, 2014

12 Victorian Building Authority, *Guide to Standards and Tolerances*, 2015

13 Tasmanian Government, Consumer Building and Occupational Services, *Guide to Standards and Tolerances*, 2017

14 Concrete Institute of Australia, *Cracking in Concrete Slabs on Ground and Pavements*, Z15, 2011

15 American Concrete Institute, ACI 224R-01 *Control of Cracking in Concrete Structures*, 2008

16 American Concrete Institute, ACI 360R-10 *Guide to Slab-on-Ground*, 2010: Figure 6.6 and Notes *Recommended joint spacing for unreinforced slabs*

17 *Placing Joints in Concrete Flatwork: Why, How and When – Contraction/Control Joints*, Portland Cement Association (available at www.cement.org by searching for article)

18 Miltenberger, M.A. and Attiogbe, E.K., Shrinkage-Based Analysis for Control-Joint Spacing in Slabs-on-Ground

19 Australian Standard AS 3600, *Concrete structures*, 2009

20 NSW Office of Fair Trading, NSW Consumer Protection Agency: Guide to Standards and Tolerances for home builders & renovators (FT242 July 2003)

21 Australian Standard, AS 3799 *Liquid membrane-forming curing compounds for concrete*, 1998

22 Cement Concrete and Aggregates Australia, Technical Report TR/F129 (December 1996)

23 American Concrete Institute, ACI 332.1R-06 *Guide to Residential Concrete Construction*, 2006: Clause 5.5.2